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PRINCIPAL CONTENTS

Generally Speaking — **Adamant** 65

The Baker-Pera Tool Grinding Attachment 66

The Friction and Wear of Diamond — **M. Seal** 67

Studies on the Surfaces of Diamond 74

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Generally Speaking

Ex Africa . . . . . .

We hear reports that, following on their discovery of valuable and workable oil reserves under the sands of the Sahara, the French have recently found indications that there may be an additional treasure there in the form of diamonds. A small number of stones has been discovered there, and there are strong expectations that further exploration will produce far greater results. It has been suggested, however, that the stones so far found were carelessly dropped by some wealthy Arab sheik, who had pitched his camp at that spot, but personally, we find it harder to believe in such lack of interest in valuable property on the part of an Arab, than in the possibility of there being a new diamond field in North Africa.

Instruments on show

The Physical Society Exhibition, held once again at the Horticultural Halls, at the end of last month, provides a really excellent show of the best and latest scientific equipment, but in conditions that are now so overcrowded that the ordinary visitor, not able to attend the special opening session for Fellows and representatives of the Press, can only see the exhibits he is interested in at the expense of great labour and effort. This seems to be a great pity, with so much that is worth seeing, particularly as there are always many new developments not to be seen in other exhibitions.

Quick sieve checking

One very interesting exhibit at this year's show was the diffraction sieve checking device shown on the Morgan Crucible stand. Although not intended for testing sieves to British Standard specification, this equipment is very suitable for making a quick and easy check of meshes, and has the great advantage of producing a direct, visual, indication of the size.

There were many other items, especially amongst the optical exhibits, of equal interest

7 MAY 58 LIBRARY

to industrial diamond users, and many others, perhaps of less direct application, but of the greatest possible interest in a general way.

Other exhibitions

Next month's issue of the Industrial Diamond Review will be very largely devoted to reports of other exhibitions which are taking place in the course of the next few weeks. This will include the Universal Exhibition of Brussels, and, in London, the IEA Exhibition and the Gauge and Tool Exhibition. We hope to cover these exhibitions, as far as they will interest our readers, very fully.

A hundred years back

We have recently been reading a French treatise on precious stones published in 1858 by Charles Barbot, who achieved a considerable amount of fame in his day on account of a claim he made of having invented a process for removing unwanted colour from rough diamonds. Nothing seems to have come of this process in the end, but much of the rest of his work remains interesting, even today. Some of his ideas, however, seem a little odd nowadays: for example, he knows no other use for diamonds in industry than for the cutting of gems, and he describes a crystalline form of boron as boron-diamond, and seems to regard it as being, in fact, an impure form of diamond. Such errors as this were probably the cause of many of the stories which were current during the last century of the production of synthetic diamonds.

ADAMANT

The Baker-Pera Tool Grinding Attachment

'It has been established beyond any doubt that the blending of straight cutting edges and the nose radii of cutting tools is a leading factor in long tool life . . .'

Fig 1. Baker-Pera tool grinding attachment.

This conclusion has been reached after considerable research by the Production Engineering Research Association and other private and public bodies. It has been proved that when the cutting edges are not truly tangential to the nose radius, then the resulting discontinuities of the edge form break down in operation. Pera have established that, by taking special precautions to grind the tool correctly, it is possible to extend the tool life considerably. As a result of their investigations they were able to design a tool radius and cutting edge grinding attachment with which accurate forms for plain cutting tools could readily be produced. C. Baker of Holborn Limited developed the optical side of the attachment, and have undertaken production of the whole unit on a commercial basis.

Operating procedure

The attachment fits easily to existing machines with the normal cutter grinding table and spindle. When set up on the machine, the base is in line with the table traverse. To aid the setting up operation, the front and rear edges of the base are ground in relation to the calibration of the angle scales. The tool to be ground is clamped either directly to the cross slide table on the attachment, or in a separate auxiliary holder, registering with the guide strip on the cross slide table. Right- or left-hand tools may be set up, the difference being that, in the plan view, the top of the left-hand tool is nearer to the microscope and against the table of the attachment. The right-hand tool is the

reverse, and the only effect on the operation is that the microscope slide must be moved a little further in focussing.

Angle setting

Side and end relief angles are set on the horizontal scale at the base of the attachment, the pillar being rotated either clockwise or anti-clockwise, according to whether the tool is for right- or left-hand. The angle is read directly from the scale, and, when set, the central clamp is locked. The side cutting angle is set on a vertical scale which reads zero when the tool holder is vertical. The side cutting angle is read off in the clockwise direction, and the stop on the spigot collar is adjusted so as to prevent counter clockwise rotation by engaging the fixed stop under the spigot. The plan angle may be set off on the other side of the zero mark by continuing the rotation of the table, after setting the first stop, until the scale zero is again reached. The second stop is then set in the same manner as the first. The angles may then be ground, using the normal movements of the table.

Grinding procedure

With the toolholder in the near vertical position, and clamped with the stop engaging the fixed stop, the side cutting and side relief angles can be simultaneously ground. By rotating the toolholder to engage the other stop, the plan and side relief angles may be ground. Using the machine table movement, the tool is passed across the wheel, and a good ground finish imparted to the faces of the tool. This finish is claimed to be superior to any obtained by simply offering the tool to the side face of a wheel, as in the case of hand grinding.

When the angles are finished, the coverplate of the microscope is swung aside, and the tool nose brought into the centre of the field of view by adjusting the cross slide on which the tool is mounted. The required radius is selected on the ringed target, and the tool adjusted so that the images of the cutting edges form tangents to the radius circle. After adjustment in this way the cross slide is clamped, and the toolholder clamped at the top of the pillar is released so that the holder may be rotated about the microscope axis. A handle is provided for rotating the holder between the stops on the collar. The tool is advanced to the grinding wheel by the normal machine table feeds, and the holder rotated between the stops until the required radius is ground. The progress of the radius grinding may be observed with the microscope from time to time, but the angular faces of the tool will touch the wheel at the moment the edges are truly tangential to the radius. This may be observed as the work progresses, and the microscope used for closer inspection.

On some occasions, the size of the tool may be such that its height exceeds the focussing distance of the microscope. In these cases the guide strip is removed from the attachment table, and the tool clamped so that its top face is to the table, regardless of the handing. The side and end relief angles are then set off on the horizontal scale, and the nose grinding carried out as described.

Capacity

The capacity of the attachment is suitable for large tools up to $1\frac{1}{2}$ in. square shanks, and the small tool auxiliary carrier will take tool shanks up to $\frac{5}{8}$ in. square. The target in the optical system is marked in increments of 0.005 in. radius, and provides direct comparative setting from 0.005 to 0.10 in. radius.

The Friction and Wear of Diamond

M. Seal*

Introduction

Diamonds for use as tools or in jewellery are normally shaped by a number of operations. The rough diamond is usually first cleaved or sawn with a high-speed metal disk charged with diamond dust to give a piece of approximately the desired size. Subsequently the diamond may be shaped by bruting, polishing, or drilling. These are grinding operations: bruting is a rough turning process involving the chipping away of diamond fragments, polishing is normally carried out with loose diamond dust on a high-speed lap, and drilling is performed with a rotating needle charged with diamond dust.

Whilst bruting is undoubtedly a chipping process, there is a good deal of evidence which suggests that attrition of the diamond during polishing, drilling, or sawing occurs in a different way. In these operations the diamond as a whole may become quite hot, and the local

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7 MAY 58 LIBRARY

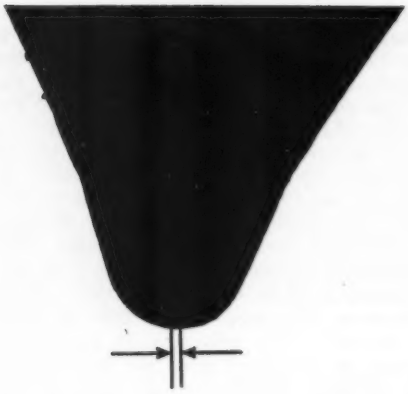
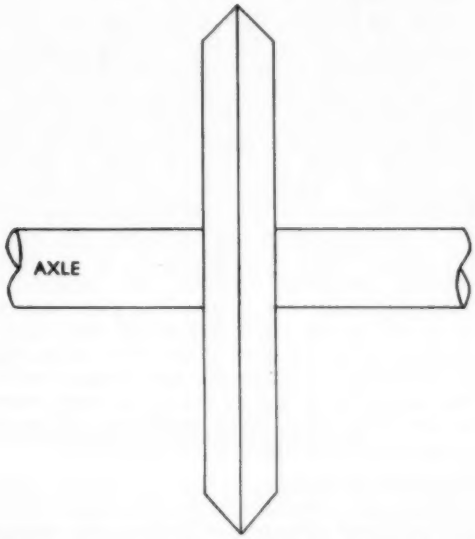


Fig 1 (Left). Silhouette of diamond stylus (width of contact between arrows, about 0.28 mm.)

Fig 2 (Right). End view of abrasion test wheel (Grodzinski and Stern).



temperatures at the points of rubbing contact of the diamond and the abrasive diamond dust are almost certainly very high indeed (Bowden and Thomas 1954).** It is possible then that the wear occurs by a thermal process such as burning or a transformation to graphite or amorphous carbon of the diamond at the 'hot spots'. Valov and Grebenchikov (1937) seem to have been the first to make such a suggestion. Later work has provided evidence supporting the theory (Grodzinski 1953, pp 215 to 225, gives a description of this work and further references). Scott (1957) suggests that a thermal mechanism is applicable in the wear of diamond on glass.

The chief objection to the suggestion of a thermal mechanism for the wear of diamond on diamond has been the apparent difficulty in such a theory of accounting for the anisotropy in the wear rate. It is found that the wear rate in the sawing or polishing of diamond depends very markedly on the crystallographic orientation of the stone with respect to the direction of abrasion. Detailed investigations of this anisotropy have been made by a number of workers (Tolkowsky 1920, Slawson and Kohn 1950, Wilks 1952, Denning 1953, 1955, and Hukao 1955). The effect is a large one: the wear rates in the directions of easiest and most difficult abrasion probably differ by a factor of 500 or more. Indeed, diamond workers consider that diamond has a grain analogous to that of wood, and an empirical knowledge of this grain has existed for centuries.

It is the purpose of the present paper to suggest an explanation of this anisotropy in wear rate in terms of a thermal theory of the abrasion. The anisotropy is believed to arise from a similar but smaller anisotropy in the friction between diamond and diamond. If simplifying assumptions are made it can be shown that the temperature rise at a frictional hot spot depends linearly on the coefficient of friction (Jaeger 1942). As the rate of thermal transformation is likely to be very sensitive to temperature, a small increase in the coefficient of friction (and thus a small increase in the hot spot temperatures) would be expected to lead to a large increase in the wear rate. The remainder of this paper will be devoted to an account of the frictional anisotropy on which this explanation is based. No attempt will be made to discuss the nature of the wear mechanism any further, as this is being done in another paper (Seal—to be published).

Experimental procedure

The friction measurements were made using the apparatus which Eldredge and Tabor (1955) used in a study of rolling friction. In this apparatus the lower of the two specimens is fixed, and the upper one can be caused to slide horizontally over it. A vertical load may be applied between the specimens, and the frictional force can be measured in terms of the deflexion of two flat springs which support the carriage on which the upper specimen is mounted.

The upper of the two specimens was normally a diamond stylus having a rounded end. A silhouette of such a stylus is shown in Fig 1.

** An alphabetical list of reference is given at the end.

The upper surface of the lower diamond, on which this stylus slid, was flat. It was usually a polished surface, but in a few of the experiments a natural octahedron surface was used. Sliding speeds were about 0.5 mm/s. The apparatus, as described by Eldredge and Tabor, was modified by Kenyon (1954), who fitted a stage which enables the lower specimen to be rotated in its own plane. This facilitates the study of the effect or crystallographic orientation on the friction. The diamonds were cleaned by degreasing in a benzene still before carrying out experiments.

It was found that two precautions had to be observed in making friction measurements on diamond. First, the friction of diamond is small, and so particular care had to be taken to ensure that the surface of the lower diamond was exactly horizontal, as otherwise gravitational effects would have introduced errors. Secondly, it was found that the friction may vary from place to place across a given diamond surface: measurements were therefore always made at the same point on a given surface.

The crystallographic orientations of the plane diamond surfaces were determined either by optical goniometry or by electron diffraction. The orientation of one of the sliders was determined from x-ray diffraction patterns.

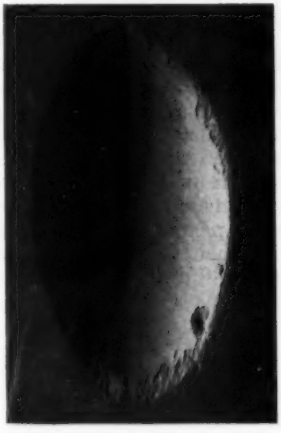


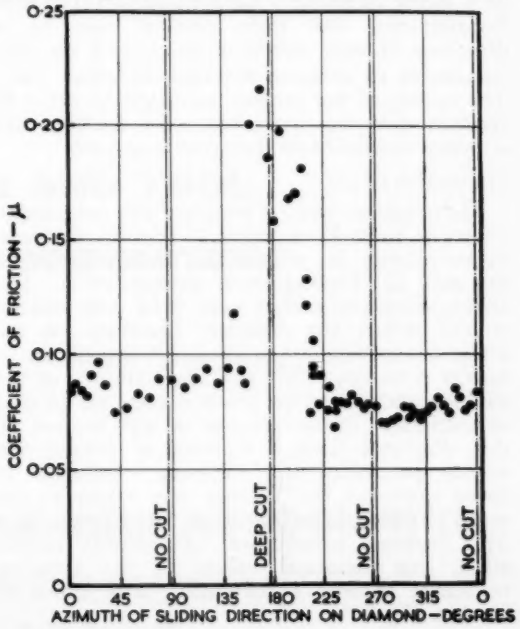
Fig 3 (Left). Groove produced on polished diamond surface by the abrasion test wheel ($m \perp \sim \times 600$: $m \parallel \sim \times 100$).

Fig 4 (Right). Friction anisotropy on diamond surface of arbitrary orientation.

There is a correlation between the directional variations in the friction and in the abrasion resistance of diamond. Measurements of rate of abrasion were made for the author by Dr P. Grodzinski. The micro-abrasion tester used (Grodzinski and Stern 1949) consists of a cast iron wheel of double conical section (Fig 2). The wheel is charged with diamond dust and is rotated at high speed (about 10,000 rev/min with a wheel of 1 inch diameter). The wheel is then lowered on to the diamond surface under test, under a measured load for a measured time. A boat-shaped depression results (Fig 3). As was first shown by Tolansky and Austin (1949), the depths of these depressions can be measured by multiple beam interferometry, and a measure of the abrasion rate obtained.

Previous work on the friction of diamond

It has been known for a considerable time that diamond has a low friction. The first scientific investigation of the factors on which the friction of diamond depends seems, however, to be that of Bowden and Young (1951). They found that the coefficient of friction μ of diamond measured in air is usually less than 0.1 and is not independent of load P. μ was found to be approximately proportional to $P^{-0.2}$. The frictional behaviour of diamond is thus different from that of metals, where Amontons' law, ' the frictional force is independent of the apparent area of contact, and directly proportional to the load ' is obeyed. The difference is probably due to the fact that the deformation at the points of contact of the sliding surfaces is elastic for diamond and plastic for metals. If the frictional force is proportional to the area of contact, then for elastic deformation μ should be proportional to $P^{-1/3}$ instead of being independent of P as with plastic deformation. Bowden and Young concluded from their results that



the deformation at the points of contact of the diamonds was probably largely elastic. The author's results support this conclusion: under the conditions of slow-speed sliding and moderate loads used in the friction experiments, no permanent damage whatever could be detected on the diamond surfaces.

A second effect was also studied by Bowden and Young. They found that the friction of diamond rises markedly, to $\mu \approx 0.5$, if the adsorbed layer of oxygen and other gases is removed by heating in a vacuum. In their experiments the diamonds were heated to 1,100 deg C (2,000 deg F); the friction was measured in the vacuum after the diamonds had cooled to room temperature. The effect is analogous to the increase in friction which occurs when clean outgassed metals slide in a vacuum (Bowden and Tabor 1954). Seizure does not occur with diamond since the large-scale plastic deformation typical of metals cannot occur. The low friction of diamond as normally measured in air is thus due to the presence of adsorbed surface films. This must be borne in mind in considering the results of the remainder of this paper, all of which were obtained in air.

It was first noticed by Kenyon, working in the same laboratory as the present author (1954), that there is an orientation effect in the friction of diamond. He found an anisotropy of a factor of about 3 on a polished (110) face. Furthermore, the high friction was in a direction of easy abrasion [001], and the low friction in an abrasion resistant direction [1$\bar{1}$0]. The results of the present investigation serve to confirm that this correlation of friction and abrasion resistance of diamond is general.

Orientation effects

The simplest way of studying the orientation effects is to make a series of friction measurements rotating the stage of the friction apparatus by, say, 10° between each measurement. The sliding direction is thus kept fixed with respect to the stylus, but different directions on the lower flat surface are studied. A typical set of results is shown in Fig 4. The azimuths of the sliding direction on the lower surface are plotted as abscissae. In the direction of high friction on this diamond (and a number of others) the sliding proceeded in 'stick-slip' fashion. In these instances the friction was taken as the mean of the values for 'stick' and for 'slip'. This diamond surface was of arbitrary orientation, but measured values of the abrasion resistance showed a correlation with those of friction (Fig 4).

Following preliminary work on diamond surfaces of arbitrary crystallographic orientation, measurements were made on an accurately oriented cube face. This face had been polished to within ½° of an {001} crystallographic plane. The vertical axis of the slider was about 4° from ⟨110⟩. The sliding surfaces therefore approximated to a dodecahedron and a cube face. It was found that the friction depended on the relative orientations of the sliding direction and of both diamonds. The results are shown in the graphs of Fig 5. Each graph is of results obtained with the orientation of the slider fixed in relation to the sliding direction, the abscissae being the azimuths of the sliding direction on the lower cube diamond surface. The individual graphs were thus obtained in a similar way to that of Fig 4. The slider can be rotated about its own axis and a series of these graphs obtained, each corresponding to a particular relative orientation of slider and sliding direction. The graphs of Fig 5 form such a series: the angles shown in each graph represent the rotation of the slider measured to an arbitrary zero.

It can be seen that the individual curves of Fig 5 reflect the fourfold symmetry of the cube face. The maxima occur when the sliding direction is approximately parallel to a crystallographic axis in this face. The magnitude of the anisotropy depends on the relative orientation of slider and sliding direction, and is greatest for the curves for stylus positions '35°' or '60°'. The plane of the sliding surfaces is approximately (110) with respect to the slider, and the [001] axis lying in that plane is parallel to the sliding direction when the slider position is 40° on the arbitrary scale of Fig 5. It seems then that we get a maximum anisotropy when the [001] axis of the slider is parallel to the sliding direction. If this is so, then the largest values of friction occur when the sliding direction is a direction of easy abrasion of both diamonds.

Further experiments

These experiments have been repeated with other diamonds. With the exception of natural octahedron {111} faces, every diamond showed frictional anisotropy. In every instance where a correlation was attempted (seven diamond surfaces) the directions of high friction were also found to be those of easy abrasion. Frictional anisotropies of a factor of 3 or more were found on particular surfaces, but a factor of 2 was more usual. The coefficient of friction was generally about 0.08, rising to 0.15 or 0.2 at the maxima. Coefficients of friction as low as 0.03 have, however, been recorded.

GAUGE & TOOL EXHIBITION

12-21st MAY, 1958

10 a.m. - 6 p.m.

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There are a few further points about the friction results which should be mentioned. On natural octahedron faces the friction was low (μ = 0.05 to 0.07) and no significant anisotropy could be found. The fourfold symmetry of friction observed on the one {100} face was confirmed on another accurately oriented {100} face. However, the fourfold symmetry is not observed if the face is misoriented by more than about 1½° from the true {100} plane; the sensitivity of rates of abrasion to misorientation of the face has been reported by Wilks and Wilks (1954). Lubrication of the sliding surfaces with stearic acid or a light mineral oil had little effect on the friction (Fig 6).

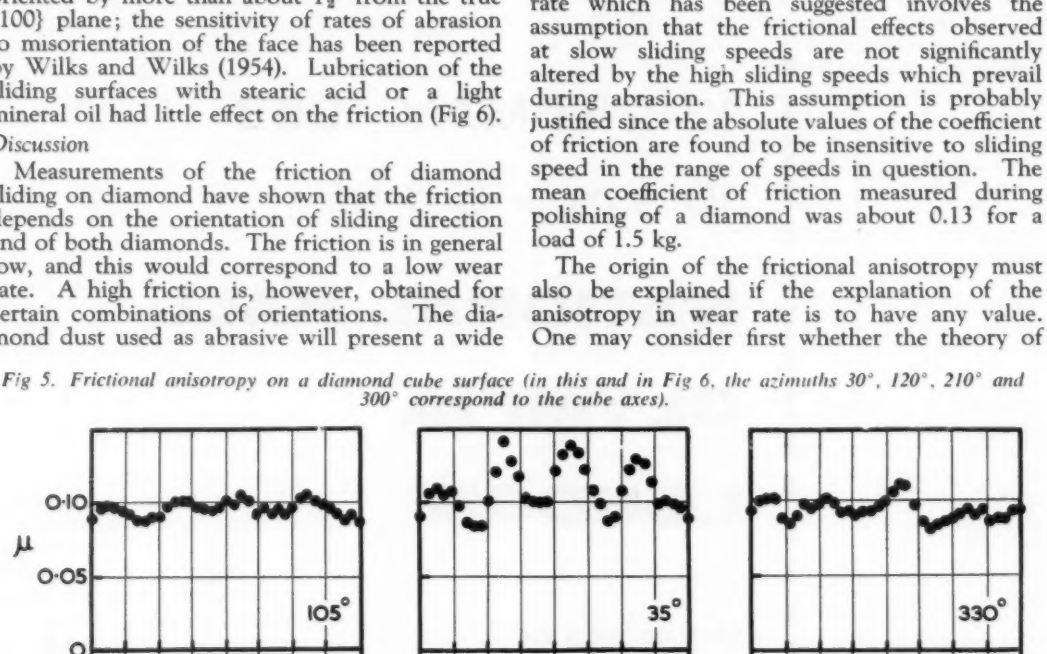
Discussion

Measurements of the friction of diamond sliding on diamond have shown that the friction depends on the orientation of sliding direction and of both diamonds. The friction is in general low, and this would correspond to a low wear rate. A high friction is, however, obtained for certain combinations of orientations. The diamond dust used as abrasive will present a wide variety of orientations to the diamond being abraded. Thus when the sliding is in the right direction on this diamond, one may expect to have a high friction between this diamond and some of the abrasive particles. A high wear rate would be expected to result. The directions of easy abrasion are in fact the directions in which the friction may be high.

The explanation of the anisotropy in wear rate which has been suggested involves the assumption that the frictional effects observed at slow sliding speeds are not significantly altered by the high sliding speeds which prevail during abrasion. This assumption is probably justified since the absolute values of the coefficient of friction are found to be insensitive to sliding speed in the range of speeds in question. The mean coefficient of friction measured during polishing of a diamond was about 0.13 for a load of 1.5 kg.

The origin of the frictional anisotropy must also be explained if the explanation of the anisotropy in wear rate is to have any value. One may consider first whether the theory of

Fig 5. Frictional anisotropy on a diamond cube surface (in this and in Fig 6, the azimuths 30°, 120°, 210° and 300° correspond to the cube axes).



friction developed by Bowden and his co-workers fits the facts for diamond as well as it does for metals and some non-metallic solids. A full account of this work on friction is given by Bowden and Tabor (1954): the main points of the theory, as applied to metals, are as follows. When two metallic surfaces are brought together under load, actual contact first occurs at a few local asperities. The pressures at these asperities are accordingly very high, and usually exceed the yield strength of the metal. Plastic flow and local welding of the surfaces then occur. The frictional force is the force required to shear the junctions so formed. It is found that the junctions are often stronger than the metals, so that the break occurs within the metal, and metal is transferred from one surface to the other. This transfer is the origin of the wear of rubbing surfaces. The function of lubricants is to separate the surfaces so that shear occurs within the liquid and wear of the metals is eliminated.

The same theory in a modified form can be applied to diamond. The deformation of the junctions is almost certainly entirely elastic during slow-speed sliding experiments at moderate loads. The actual area of contact will still be only a fraction of the apparent area of contact. At the asperities the stresses will be high, and it may be that two diamond lattices come into actual contact. If this is so, the diamonds would be expected to adhere, and the origin of the frictional force is explained. The anisotropy could be accounted for by supposing differences in the adhesion of diamonds in different relative orientations, and differences in the shear strength of the junctions in different directions. It is perhaps significant that on {110} and {100} faces, directions where the friction is always low, are also close packed directions of the diamond lattice.

However, the diamond surfaces are normally covered with adsorbed layers of gas. Bowden and Young (1951) showed that the friction of clean outgassed diamonds is high. The considerably lower friction of diamonds sliding in air suggests that the conditions here are those of sliding of one adsorbed gas layer on another, rather than those of sliding diamond on diamond. It would seem also that the adsorbed layers are very firmly attached to the diamond, as would be expected from the high bond strength, and thus surface energy, of diamond. It may be, however, that the diamonds penetrate these layers and come into actual contact in a few places, the higher friction on outgassing being due to the larger area or number of points of actual contact. Indeed, if the anisotropy is

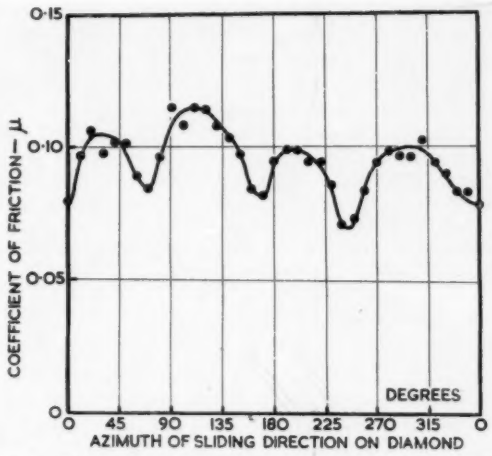


Fig 6. Frictional anisotropy on a diamond cube surface lubricated with light mineral oil.

to be explained on this model, this must be so. Nevertheless, the strength of these junctions must be less than that of the diamond as a whole, since no evidence of permanent deformation, transfer or wear has yet been detected on diamonds after sliding under the conditions of the friction experiments. This would be expected, for the region where two diamonds of different orientation join and adhere would, to say the least, be a highly dislocated one.

Other possible explanations of the origin of diamond friction have been considered, but none is satisfactory. Thus, it is perhaps natural to try to associate the anisotropy in friction with the elastic anisotropy of diamond. The elastic moduli are fourth-order tensors and are, therefore, anisotropic in a cubic crystal. However, it is not easy to account in detail for the frictional anisotropy in terms of the elastic anisotropy. The area of contact between a diamond stylus with spherical tip, and a cube, dodecahedron, or octahedron diamond surface is approximately circular (Howes and Tolansky 1955) and so, no matter what the direction of sliding on such a face, the width of the track is always the same. Also, owing to the high symmetry of the cube face, a number of the elastic moduli which might be expected to be relevant are isotropic as regards directions in that face.

One might possibly explain the sliding friction of diamond as arising from elastic hysteresis losses: such an explanation would be similar to that put forward by Tabor (1955) to account for the phenomena of rolling friction. However, the absolute magnitude of the coefficients of sliding friction of diamond are probably too large for

this hypothesis to be tenable. Also the rise in friction on outgassing diamond surfaces would not be readily explainable.

The hypothesis that the frictional anisotropy arises from unidirectional structure on the diamond surfaces has also been investigated and has been found to be untenable. It is concluded that the friction arises from adhesion of the diamonds, that the junctions are weaker than the diamonds in bulk, and that the frictional anisotropy arises from directional differences in the strength of the junctions.

Acknowledgements

The author thanks Dr F. P. Bowden, CBE, FRS, for his interest and encouragement; Tube Investments, Ltd, for a research fellowship; Industrial Distributors (1946) Ltd, for a grant to the Laboratory and for the loan and polishing of the diamonds, and Miss H. M. Murphy of the Cavendish Laboratory for taking the x-ray diffraction patterns determining the orientation of the slider.

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Studies on the Surfaces of Diamond

This year's annual Herbert Smith Memorial Lecture was given to the Gemmological Association of Great Britain on April 2, by Prof. S. Tolansky, FRS, at the Science Museum, South Kensington, London, SW7. On March 2 his subject was "Studies on the Surfaces of Diamond."

An account was given of selected aspects from original work carried out by the lecturer during the past 10 years on three broad aspects of microstructures of diamond surfaces. These included (a) micro-studies on the shapes and distributions of the trigons on octahedral faces, (b) investigations on the etching of diamond, (c) an experimental study of the production of percussion marks on diamond. The lecture was illustrated with 50 slides covering a comprehensive field.

The precision interferometric optical techniques specially developed for the purpose by the lecturer were first explained, and it was shown

Fig 1. A typical example of beautiful contour patterns of trigon formations on the surface of diamond, photographed by a technique which is capable of revealing height variations of one twenty-five millionth of an inch.

how these produce on a diamond surface a microtopographical "contour map." This resembles the familiar contour map of geography but the optical contour lines (called multiple-beam interference fringes) represent height changes of a mere 1/100,000th in. It was demonstrated that the technique is capable of such a refinement that height variations of only 1/25,000,000th in. can be revealed. Many beautiful contour patterns of trigon formations on diamond were illustrated. Fig 1 is a typical example. Numerous other applications, including the crossed fringe techniques were described.* (Fig. 2).

The lecturer emphatically insisted that all of several hundred octahedral faces he had studied exhibit growth trigons. He considered that they were a basic **growth** mechanism in octahedral forms of diamond, and could not accept solution mechanisms as responsible for them. The microstructures of some dodecahedral faces were surveyed briefly. The topographies of diamond cleavages were discussed and attention drawn to a cleavage difference which these experiments revealed between the type I and the type II diamonds.

The directional hardness of polished faces of diamond has been studied by grinding micro-cuts in different directions, and it was shown that the interferometric assessment of the volumes of the amounts abraded out of these micro-ruts gives a good measure of the directional resistance to abrasion.

The method developed by the lecturer for lightly **etching** diamond surfaces were described in detail, and it was shown that a mild etching results in the production of etch patterns which throw a great deal of light onto both the character of the surfaces and also the history of **internal** growth of the diamond. This is a new approach

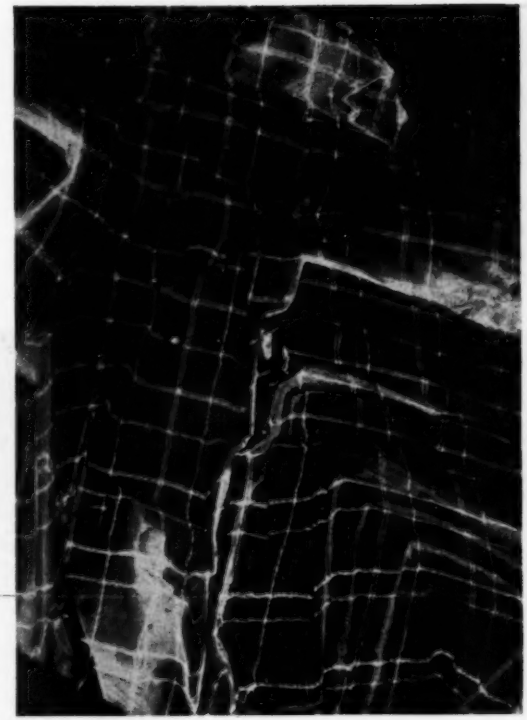

Fig 2. Double-crossed fringes on the surface of a diamond. One set of high dispersion fringes crossed by two perpendicular sets of low dispersion fringes on the octahedron face. The effect is to produce a dramatic contour picture for study.

of some considerable value and is likely to be very profitable in future research. The evolution and development of triangular etch pits on octahedral faces (these are always oppositely oriented to the well known growth trigons) was demonstrated by illustrating the effects of successive grades of slow etch, starting at 500° and going

* For technical details see "Microstructures of Diamond Surfaces," by S. Tolansky (N.A.G. Press Ltd, London, 1955).

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up to 700°C. At an etching temperature of about 650°C. most remarkable etch "block" patterns develop on a micro-scale. Thus for example Fig 3, at a magnification of X2250 shows the characteristic block pattern formed on an octahedron face. This pattern is only fully realised when high magnification is employed. When looking at the surface with the ordinary watchmakers' eyeglass, the surface presents a mere "drusy" appearance, a sort of matt low-reflectivity, but in fact this is due to the light-scattering effect of the block pattern.

Illustrations were also given of the boat-shaped etch pits which can be produced on dodecahedral planes, and of the regular square-shaped pits which appear on cubic planes of diamond, all of which is of course in strict accord with crystallographic symmetry considerations. Some of the more striking etch patterns illustrated were secured by the mild etching of octahedral *cleavage* surfaces. It was established that notable, often highly complex, rectilinear etch patterns form on such cleavage faces, an example of which, under high magnification, is shown in Fig 4. The most important fact established by these experiments, was the

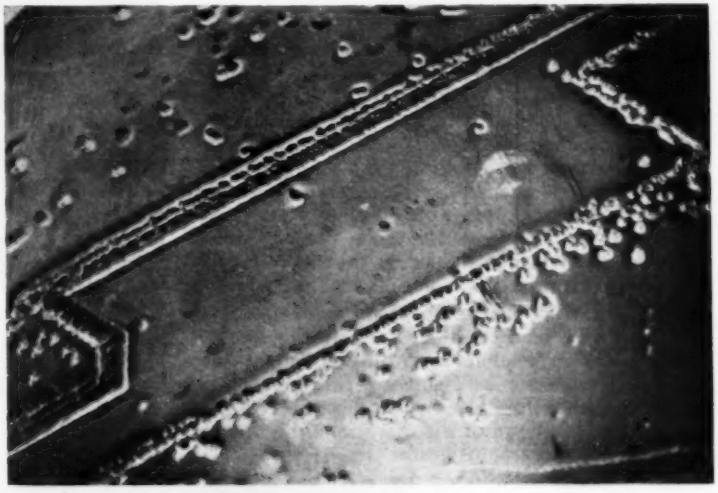

Fig 4. A striking etch pattern achieved by the mild etching of an octahedral cleavage surface.

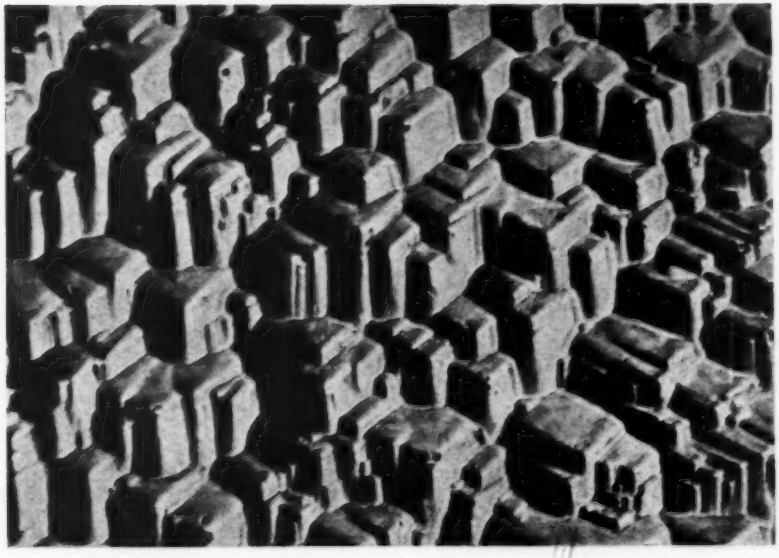

Fig 3. The octahedron face of a diamond etched at about 650° C. These remarkable "block" patterns are on a micro-scale and are not fully realised except under high magnification. This particular example is at 2250 × magnification.

discovery that there is exact one-to-one *oppositely matched* faces separated by cleavage. No matter how complex the pattern appearing on a cleavage face, it is exactly matched in mirror image on the opposite face separated by the act of cleavage. The bearing of this valuable observation on the character of the internal structure of the diamond was discussed in some detail. These experiments establish with certainty that the crystals studied were originally laid down in thin parallel sheets, parallel to the octahedral plane.

The discourse ended with an account of some studies made on the artificial induction of percussion marks on diamond faces. It was shown that application of quite small loads (a few pounds weight) on a diamond ball pressed onto a plane diamond octahedral face leads to the production of a small crystallographically oriented regular hexagonal shaped percussion "ring-crack." On dodecahedral planes hexagonal ring-cracks also arise, but of less symmetry than on octahedral faces. On cubic planes an approximately square-shaped crack tends to form. These percussion marks can be accounted for in terms of easy directions of cleavage.

The way in which the cracks evolve was demonstrated with pictures of their onset, taken by regularly increasing the loads from zero load. By the use of precision interferometry (and very precise techniques are needed for this) it has been established that the ring-crack has a flat interior base and is surrounded by a *very slightly* raised ledge. The heights of these ledges are astonishing small, often a mere one-millionth of an inch. Nevertheless the crack so formed can become the weak-spot nucleus of a failure or fracture. The bearing of this on the fracture of diamond machine tools was discussed.

A report was given on a careful microscopic examination of a number of gem-quality octahedra, and it was established that most faces have on them several minute oriented ring cracks. These are in fact quite common, even on most of the high quality stones studied. It is conjectured that the mining crushing processes may be connected with this, since experiments show that it is not necessary to press diamond on diamond to produce a ring-crack, such diamond cracks being formed by other hard material such as silicon carbide, or ruby pressed on diamond.

Bench-grinding and Lapping Machine and Spark Erosion Machining Equipment

A demonstration was recently given at the Gloucester factory of Impregnated Diamond Products of two new machines lately developed by this company. Both of these machines are being produced by Impregnated Diamond Products in conjunction with Wickman Ltd., of Coventry, and they have been thoroughly tested in working conditions before being introduced to the public.

The Wickman-Neven GF/O bench grinding and lapping machine is intended for production of an accurate finish on carbide tools. The grinding head of this machine is oscillated to and fro by a small motor mounted at the rear, so that the tool which is being ground can be mounted in one position without fear of producing a groove on the surface of the grinding wheel. The accuracy of finish obtainable in this way gives a great increase in tool life, whilst the avoidance of damage to the wheel surface may improve the life of the grinding wheel by as much as 30%. The wheel normally moves across the surface of the tool at 30 strokes per minute, but, if required for grinding curved

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surfaces, this motion can be completely cut out and the machine used as a standard off-hand grinding machine.

The other machine, which was demonstrated at the same time, is a development of the same company's Sparcatron spark erosion machining equipment, and is known as the Sparcard. Although the electrical circuits and the principles of operation of this machine are closely connected with the original Sparcatron, the results, in fact, are exactly the opposite, and instead of the removal of material from the workpiece, deposition of a thin layer of hard metal, such as tungsten carbide, on the working surface takes place. This enables advantage to be taken simultaneously of the longer life in conditions of abrasive wear of the hard metals, and of the toughness and greater resistance to shock of such metals as high speed tool steel. Field tests carried out in the machine shops of a number of well-known engineering companies indicate that an average increase of tool life of 60% can be expected, even when machining such difficult metals as the Nimonic 100 and Nimonic 90 alloys. This process appears to have great prospects in a number of applications, and experiments are still being carried out both as regards the metals used for workpiece and for deposit, and also as regards the type of tools to which the process can be suitably applied.

Universal Glass Cutting Tool

The Wilson Diamond Tool Co Ltd have notified us of a new tool for use in glass cutting. A diamond tool is mounted on the end of an extendible arm, and the other end of the arm is mounted on a $\frac{3}{4}$ in. plywood template, by means of a screw. The template should be $\frac{1}{2}$ in. smaller all round than the shape to be cut; this distance compensates for the $\frac{1}{2}$ in. distance between the contour follower, *ie* the perimeter of the diamond cutting head, and the diamond. The cutting head will revolve round any concave or convex radius down to 2 in., and is easily removable for resetting of the diamond. The makers claim that all pieces cut from one template will be the same size, and will thus reduce grinding and fitting time. The maximum capacity of the tool is a 36 in. square. The sole selling agents are Emile Regniers & Co (London) Ltd., 4 Broad Street Place, London EC 2.

Diamonds Feature in Philadelphia Exhibition

A display of diamonds is expected to prove a very popular feature at the American Society of Tool Engineers' Exhibition which will be held in Philadelphia from May 1-8, 1958.

The display will include a collection of stones chosen to represent the proportion of each quality recovered from a mine. The Industrial Diamond Association of America, Inc., is exhibiting at the show, and the experience they gained in 1956 at Chicago should help them to provide something that ASTE members—and the public—will be interested to see. The 1956 exhibits were shown at the ASTE Annual Exposition, and the diamond exhibition was arranged by the Diamond Research Laboratory, sponsored jointly by the Armour Research Foundation, the ASTE, and the Industrial Diamond Association of America, Inc. This year the Armour Research Foundation will be giving a demonstration of the sawing of diamonds and the orientated setting of stones.

The death occurred on April 15 of Mr. A. J. Hewitt, OBE, Director and General Manager of the Coventry Gauge and Tool Co. Ltd. Mr. Hewitt had been associated with the company for over 40 years.

Habit Diamond Tooling Ltd., Fulham, London, have just presented two of their members with gifts of appreciation (one chose a Hoovermatic washing machine and the other the large Electrolux refrigerator) after 10 years' service.

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ADVERTISERS' INDEX

	Page
Blackwell, W. Oil Co. Ltd., ...	77
De Vries, L. & Son Ltd.	75
Diamant Boart	79
Drukker, D. & Zn. N.V.	64
Gauge & Tool Makers Association	71
Habit Diamond Tooling Ltd.	Cover III
Henderson Diamond Tool Company, Ltd., The	78
Impregnated Diamond Products Ltd. ...	Cover IV
Indusmond (Diamond Tools) Ltd	63
Industrial Diamond Co. (Sales) Ltd. ...	Cover II
Smit, J. K. & Sons (Diamond Tools) Ltd. ...	61
Triefus & Co. Ltd.	Cover I
Vaughan, Edgar & Co. Ltd.	79
Wolverhampton Diamond Die & Tool Co. Ltd.	63

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